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An electrical network model of plant intelligence

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Abstract : A simple electrical network model, having logical gate capacities, is proposed here for computations in plant cells. It is compared and contrasted with the animal brain network structure and functions.

Keywords : Artifcial intelligence, neural networks, logic gates, membrane I-V characterestics, plant vacuolar membrane.

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1. Introduction

Considerable investigations and efforts have been made in understanding how the animal and human brains compute and recognize various spatial and temporal patterns [1,2]. The essential model consists of a network of large number (about 10^{12} in case of human, 10^{6} in case of birds) of two state electrical devices called neurons which are capable of just summing over the various (milli-volt order) input electrical pulses for a short synaptic period (of milli-second order) collected by the (10^{6} or so) dendrites of each neuron, and comparing this sum with a threshold. The synaptic interactions among the neurons develop during the "learning" process, and can be both excitory or inhibitory, rendering the network randomly frustrated. The computational capabilities emerge out of the collective dynamics of the network, which is nonlinear (due to the threshold behaviour of each neuron). For symmetric interactions, one can define an energy function (or free energy at finite noise or "temperature" level) for the network and the local free energy minima corresponds to the various local attractor patterns or memory states of the network (Hopfield [1]). For long-range interactions, the statistical physics of such a network is analytically tractable to a large extent (Amit *et al* [1,2]). The processing of informations in such network models and their detailed analysis are now established (see *e.g.*, Nishimori [2]). These demonstrated capabilities of such networks are of course very limited in their emerging computational abilities [2] and far short of anything like consciousness, where some aspects of quantum mechanics (entanglement in the molecules in micro-tubules of a single neuron) are speculated to be involved [3].

Are the plants around us intelligent? Do they also deserve our attention in this context of modeling for information processing and computation? Operationally, intelligence would mean self-adaptive behaviour under changed environments. Plants indeed have remarkable adaptability, and therefore some computational ability to adjust their response accordingly, inchanged environments. Imagine the response of a plant in a suddenly darkened area where the sunlight comes only from an angle, or of a creeper plant climbing up a window grill or a pillar with its tentacles or branches. Imagine the amount of computations involved in 'recognizing the structure' of such neighborhood before adjusting its response! They survive in every landscape of this earth, representing almost 99% of its biomass. Such marvelous adaptive behavior must be interpreted to be intelligent; although naive definition of intelligence seem to involve movement of the animal (either bodily or part of it) and plants can not move (bodily) [4]. How such intelligent behaviour of mindless plants, having no brain, compare with those of animals [5]? Plants do not have neuronal cells either.

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2. Model

Almost eighty years back, Bose detected electrical signalling between plant cells in coordinating its responses to the environments [6,7]. Although the chemical diffusion of (uncharged) molecules is a dominant source of signalling between the plant cells, it is a very slow mode. It is now established [7] that some signals are transmitted within the plants at much smaller time scale (with signal velocity about 30–400 mm/sec, depending on the plant and its environment). Such fast transmissions are due to electrical pulses, generated by ionic motions within the plant cells. Although not the dominant mode, except in some very sensitive plants like Desmodium or Mimosa [7], the electrical mode (due to migration of Ca^+, K^+, *etc.* ions) generally present in the cells of all the plants [8]. However, these electrically excitable plant cells do not have many dendrites, like for the neurons, nor are they connected by random excitory/inhibitory (frustrating) interactions.

In absence of the highly connected (frustrated) net work of neuron-like units, as in the animal brains, the plants might be utilizing the non-linear current (I)-voltage (V) characterisitcs of their cell membranes for the logical operations (gates). In fact, the plant vacuolar membrane current-voltage characteristics [9] is now established to be equivalent to that of a Zener diode, as indicated in Figure 1.

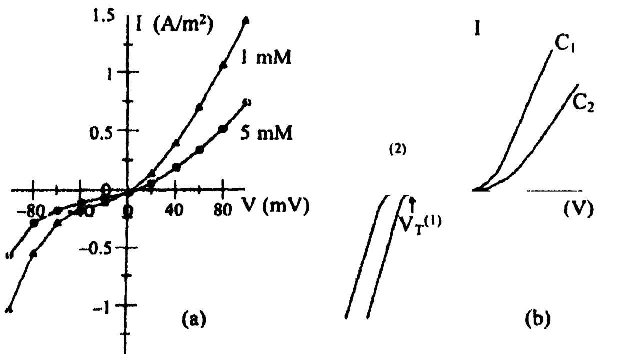

Figure 1. (a) Two typical I-V curves of the plant vacuolar membrane fast-activating channel (from [9]). The current being mainly due to Ca^+ ions and the (reversible) effect of divalent Putrescine ($C_4H_{14}N_2^{2+}$) are shown at different concentractins (c). (b) The equivalent Zener diode-like behaviour of the membrane, where the Putrescine concentrations modulate the changes in the threshold voltage V_T.

One can utilize such a threshold behaviour of the plant cell membranes to develop or model gates for performing simple logical operations. In Figure 2, such a model network containing four such threshold units; one in the output and the other three in the input. Each of these threshold units is modeled as a binary unit, having two states : 0 and 1. The inter-unit connection strength is denoted here by the matrix W. The output O of the network considered can then be expressed as

$$O = \theta\,(I - \Phi), \tag{1}$$

Where θ is the step function ($\theta(x) = 1$ for $x \geq 0$; and 0 otherwise),

$$I = W_1 I_1 + W_2 I_2 + W_3 I_3, \tag{1a}$$

and F is the threshold strength (determined by the threshold voltage V_T) for the output unit. I_1, I_2, I_3 are the inputs to the three input units and W_1, W_2, W_3 are their connectivity strengths with the output unit, as indecated in Figure 2.

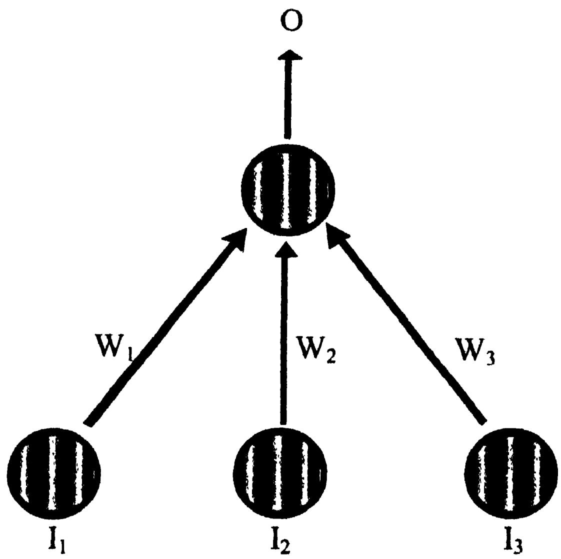

Figure 2. A simple network containing four threshold units (three in the input and one in the output) for performing logical operations like AND, OR, NAND, *etc*

For different combinations of I_1, I_2 and I_3, the outputs for defferent logic gates are given in the Table 1. These can be easily achieved using the combinations of inter-cell connections and the output cell thresholds as :

$$W_1 = W_2 = W_3 = 1, \ \Phi = 3, \tag{2a}$$

for the AND gate;

$$W_1 = W_2 = W_3 = 1, \ \Phi = 1, \tag{2b}$$

for the OR gate; and

$$W_1 = W_2 = W_3 = -1, \ \Phi = -2, \tag{2c}$$

for the NAND gate.

Table 1. The input-output (truth) table for the logic gates

Inputs			Outputs O		
I_1	I_2	I_3	AND	OR	NAND
0	0	0	0	0	1
0	0	1	0	1	1
0	1	0	0	1	1
0	1	1	0	1	1
1	0	0	0	1	1
1	0	1	0	1	1
1	1	0	0	1	1
1	1	1	1	1	0

3. Discussions

These gate capabilites of simple networks of the plant cell membranes, using their nonlinear characteristics and consequent threshold behaviour (with adjustable thresholds through changed concetrations of, for example, the Putresicne and the interaction matrix W) would allow (*cf.* [2]) simple computations in the electrical channels of the plants. It may be noted that such networks here are much more local and tiny in structure, compared to the massively connected and parallelly working network of animal brains. Also, the network matrix W elements are either all positive (excitory) or all negative (inhibitory) in eqns. (2). As such, they do not involve any frustrations as in the animal brains and have got consequently several limitations in their computational capabilities; for example, they lack the distributed parallel computational capacity, associate memory, *etc.*

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References

[1] J J Hopfield *Proc Nat Acad Sci* (USA) **79A** 2554 (1982), D J Amit, H Gutfreund and Sompolinsky *Ann Phys* **173** 30 (1987)

[2] For review see *e g*, J Hertz, A Krough and R G Palmer *Introduction to the Theory of Neural Computation* (Reading MA : Addison-Wesley) (1991), B K Chakrabarti and P K Dasgupta *Physica* **186** 33 (1992), H Nishimori *Statistical Physics of Spin Glasses and Information Processing* (Oxford : Oxford University Press) (2001)

[3] R Penrose *The Emperor's New Mind* (Oxford : Oxford University Press) (1991); M A Nielsen and I L Chuang *Quantum Computation and Quantum Information* (Cambridge : Cambridge University Press) (2002)

[4] A Trewavas *Nature* **415** 841 (2002)

[5] B K Chakrabarti *Proc Asiatic Soc* (Kolkata) (in press); also at arXiv:cond-mat/0205094 (2002)

[6] J C Bose *The Nervous Mechanism of Plants* (London : Longmans, Green) (1923)

[7] V A Shepherd *Current Sci.* 77 189 (1999)

[8] T Genoud and J-P Mètraux *Trends in Plant Sci.* **4** 503 (1999)

[9] L I Brüggemann, I I Pottsin and G Schonknecht *The Plant J.* **16** 101 (1998)